INTERNET DOCUMENT INFORMATION FORM

A. Report Title: Logistics For The Joint Strike Fighter – It Ain't Business As Usual

B. DATE Report Downloaded From the Internet: October 18,1999

C. Report's Point of Contact: (Name, Organization, Address, Office Symbol, & Ph #): DEPARTMENT OF THE AIR FORCE
AIR FORCE JOURNAL OF LOGISTICS
501 WARD STREET
GUNTER ANNEX
MAXWELL AFB, AL 36114-3236

D. Currently Applicable Classification Level: Unclassified

E. Distribution Statement A: Approved for Public Release

F. The foregoing information was compiled and provided by:
DTIC-OCA Initials: __pm__ **Preparation Date OCTOBER 18, 1999**

The foregoing information should exactly correspond to the Title, Report Number, and the Date on the accompanying report document. If there are mismatches, or other questions, contact the above OCA Representative for resolution.

Logistics for the Joint Strike Fighter—It Ain't Business as Usual

Gary Smith
J. B. Schroeder
Barbara L. Masquelier

Introduction

The Joint Strike Fighter (JSF) program is the focal point for defining the next generation of strike aircraft for the Air Force, Navy, Marines and US allies. The focus of the program is performance, balanced with affordability—reducing the costs of development, production and ownership of the JSF family of aircraft. In addition to affordability, three other pillars have been established for the JSF program: survivability, lethality and supportability/deployabiltiy. These four pillars provide the foundation for the design and development of the JSF weapon system.

One of the keys to providing an affordable approach to supportability and deployability lies in the strategy of *Prognostics and Health Management* (PHM) and how it supports the concept of *Autonomic Logistics (AL)*. The foundation for this approach was developed during the JSF Concept Exploration phase with the *Advanced Integrated Diagnostics*[1] (AID) study. The study effort reviewed current aircraft systems and available technologies for promising techniques in prognostics, diagnostics, sensors, diagnostic design tools, maintenance systems and software systems. The product of the AID study was a technology insertion and investment plan that can provide broad reliability and maintainability benefits for major strike weapon systems through the use of advanced diagnostics. With increasing computing and sensing capabilities, moving from a reactive, diagnostic environment to an anticipatory, prognostic system health management paradigm is now feasible.

The Advanced Strike Integrated Diagnostics[2] (ASID) program followed in the JSF Concept Development phase. It provided a definition, design and simulation of an advanced diagnostics architecture. As part of the ASID program, a collaborative Integrated Program Team, led by the Air Force, was established to participate in formulating the architecture. The team included experts from the Navy, TRW, the University of Dayton Research Institute, Lockheed Martin, McDonnell Douglas, Boeing, Northrop Grumman, General Electric and Pratt & Whitney. The developed architecture has the potential to improve reliability and maintainability (over that seen in current systems) by applying diagnostic technologies that achieve 100 percent fault coverage. As envisioned, this would be done through a mixture of on-board and off-board techniques.[3,4] The architecture addressed cost, schedule, benefits and resources that would be required in subsequent phases of the program as well as estimated life cycle cost savings. Architecture features—such as the diagnostic design process, benefits of integrated information flow and feedback between operations, support and design functions—were found to be important attributes. The products of the ASID program were the computer simulation verifying the architecture concept and a road map of technologies and products that need to be exploited in the JSF Concept Demonstration phase.

The AID and ASID programs laid the foundation to support the concept called Autonomic Logistics, an integrated, automated architecture for total vehicle support. This article focuses on the contribution of Prognostics and Health Management, the Joint Distributed Information System (JDIS) and the JDIS relationship to an AL system.[5,6]

Approach

The JSF autonomic support concept is more than the typical number of people, equipment, spares, bombs, bullets and life-support considerations included in a military support system. It is analogous to the autonomic nervous system that directs the body to *breath in and breath out* without being told to do so. The autonomic logistics infrastructure responds with minimal human interaction—making decisions at each step of the sortie generation and maintenance cycle. For the autonomic logistics support concept to work, there must be a stimulus to trigger the system. The Prognostics and Health Management system being developed for the JSF Air Vehicle is the main stimulus that triggers a spontaneous response that sets the AL system in motion.

One of the unique features of the JSF is the timing of the stimulus provided to the AL system. In present systems, the aircraft is *debriefed* only after return from the mission. After landing, the parts, tools and equipment needed to ready the aircraft for the next mission must be ordered, acquired and positioned in order to perform maintenance and service. A Passive Aircraft Status System (PASS) under development for the JSF Air Vehicle will make it possible to simulate the AL system prior to an aircraft's return from a mission. As a result, tools, equipment and personnel can be prepared to perform maintenance before the aircraft lands. Also, in present systems, the human must rely on multiple, diverse sources of information from the aircraft, the pilot and a debriefing system that may or may not focus on the fault in making decisions on corrective actions. PASS relies on an integrated report from the on-board prognostic and diagnostic system that minimizes incorrect maintenance actions and decreases support response requirements.

Getting an aircraft ready to service prior to landing has several other advantages as well. For example, the on-board diagnostic system may report a fault or a fault indication the technician is not familiar with. The AL system provides the capability for maintenance rehearsal prior to actually

performing the maintenance event. While the maintenance technician is working through the event rehearsal, spare parts are ordered. As a result, the technician is armed with both the necessary parts and the experience to perform the fault isolation and repair the malfunctioning system before the aircraft arrives. This allows the aircraft to be returned to *fully mission capable* status far more quickly than is possible with current systems, thus improving sortie generation.

Environment

In today's environment, all US military campaigns are, by definition, joint and require coordinated efforts during operations. However, the logistics support systems for each of the Services contain unique solutions to their individual logistics needs that are not coordinated. Each Service independently determines the support materiel, and the quantities, must be moved into a theater of operations both before and during actual operations. This method of forward stocking of materiel, while effective, is inefficient, contains redundancies and can introduce unnecessary time lags. It can also restrict operational choices and limit when operations begin.

The current logistics support system is reactive versus proactive. This type of system does not anticipate imminent demands for support materiel, personnel or training. It knows what happened yesterday, but it is inadequate in anticipating tomorrow's demands. Because of this, additional parts, support equipment and personnel are required to achieve an acceptable mission capability rate and reduce the risk of in-flight failure. It is also a system that has traditionally relied on *brute force* logistics techniques for supporting campaigns or operations. The use of brute force logistics techniques requires a larger than necessary amount of spares be taken into a theater of operations, additional support equipment and personnel and progressively delivering support materiel while an operation is ongoing. This type of logistics system is not able to think or act on its own. It is also very labor intensive in making decisions and ordering support materiel, cannot translate operational and maintenance data into a decision or action and requires intense human interaction to make decisions at every level of indenture.

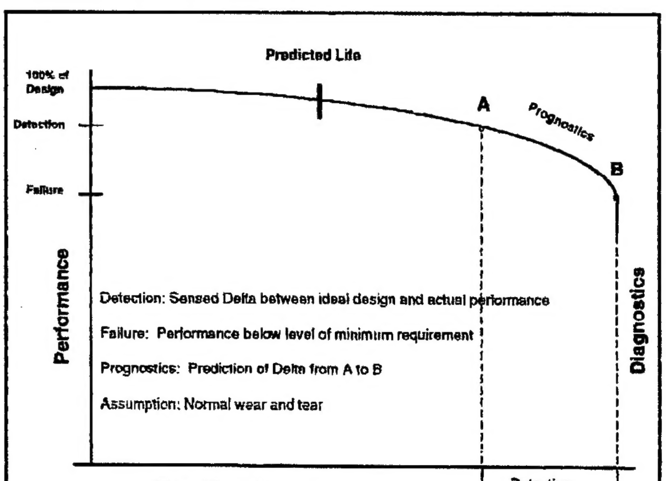

Figure 1. Prognostics Definition

Goals of an Autonomic Logistics System

What are the system characteristics that will enable an autonomic support system? An AL system must be designed with a PHM concept as part of the system engineering process—keeping in perspective the level of reliability, diagnostics and maintainability the system will need and can afford, as well as how the solution fits into the overall support concept. The vision for PHM in the environment of autonomic logistics relies on the connected nature of the system architecture. PHM, the capability of anticipating when a failure will occur, is important in preventing critical failures in flight and allowing the AL system to schedule projected maintenance tasks. This will require the propulsion system, for example, to be equipped with a prognostic capability that will enable the aircraft to leave the end of the carrier deck with the assurance that the mission will be successfully completed. The health management aspect of the system attends to every fault detected. PHM and AL ensure quick return to service of the vehicle, comprehensive data flow to stakeholders in maintenance, operations and logistics and data storage for subsequent analysis. Prognostic data acquired from in-flight and ground support elements of the system will be available for use in diagnosing and performing fault analyses at all levels of maintenance. This will require the various elements of the AL system (both on-board and off-board) to interoperate. Interoperability can only be affordably achieved by designing the AL system in a top-down fashion from the onset of the design cycle and in full coordination with all other aspects of the engineering design process.

Prognostics and Health Management

To help in defining system needs and the parameters that will give an early indication of an imminent failure, the chart in Figure 1 has been functioning as a working definition of prognostics. In any system, there will come a time when performance will begin to degrade. It is the objective of prognostics to sense changes in the system, predict how long the system can function and still give acceptable mission performance and provide operators and maintainers with the projected lead time to schedule appropriate maintenance. This capability will be crucial in the JSF environment where brute force redundancy will be replaced by reliability and prognostics.

Since the system design process is geared to the elements that are common in the world of fault detection and fault isolation, the tools useful for failure analysis will be the starting point for developing a prognostic capability. The same holds true for managing the health of the vehicle and the methodology for cradle-to-grave support. Reverting to the basics of system engineering, the tools for analysis and trade studies need to be applied to sensing, testing, communicating and archiving results to arrive at the final weapon system supportability design.

Coverage and Integration

In order to achieve desired JSF support system goals, the PHM system design process, mature prognostic/diagnostic technologies and defined interactions with the existing infrastructure must be in place. Figure 2 shows that all of the pieces of weapon system supportability must fit together to yield a cohesive weapon system prognostic/diagnostic and

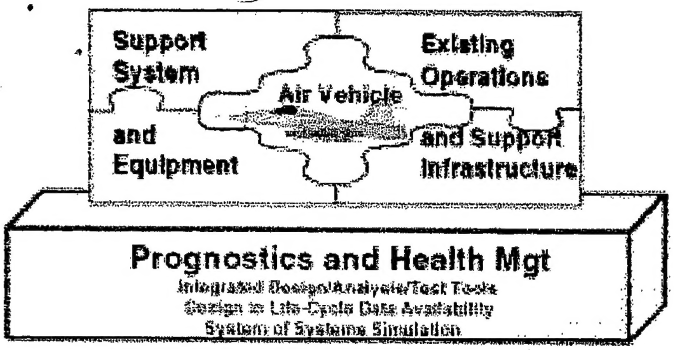

Figure 2. Weapon System Supportability

autonomic support system. Integrated design provides the solution for fitting the puzzle pieces together.

System simulation and analysis will provide the means to a design of the PHM system that will enable the JSF AL system. It is the mechanism to get end users involved early in the design phase in order to ensure the *as designed* PHM and logistics systems meet the needs of the warfighters, enable efficient *what if* analyses to properly determine requirements flow-down/allocation and enable efficient bottom-up design verification.

Feedback

Information availability will be essential to meeting all of the JSF program goals. Performance improvement goals can only be met when feedback is available to the responsible elements and changes made. All of the elements of total life-cycle support currently exist in varying states of maturity and integration. Table 1 illustrates the state of diagnostic/prognostic technology, the direction it is moving in and a notional goal for the JSF. The ultimate goal is to be able to react to actual events with real-time product and process improvements.

Elements	Existing Methods	Developing Methods	JSF Objectives
Fault Prediction (Prognostics)	Fixed estimate of life based on statistical projections.	Improved health monitoring and algorithm development.	Real-time estimate of remaining life assessment by tail number.
Fault Detection	On-board Built-In-Test plus performance evaluation.	Additional Built-In-Test and data capture, for example, F-22/V-22.	Intelligent System Detection.
Fault Isolation	Generally post fight with some fault tolerant redundancy. Remote Engineering Function.	Electronic Technical Orders aid traditional fault tree isolation.	Reasoner Based.
Fault Analysis	Paper instructions and ground support equipment. Remote Engineering Function.	Same	Reasoner Based.
Fault Correction	Engineering Change Proposal process.	Same	Real-time process using knowledge-based Infrastructure.

Table 1. State of Existing Technology

Joint Distributed Information System

The JDIS concept is the heart of the JSF information system (Figures 3 and 4). It is what the JSF logistics and support environment will require to facilitate an information management system that enables autonomic support. In it, the JDIS serves as an *information conduit* that allows for multiorganization, multiservice and multinational information system interoperability. In support of JSF user applications requesting data, JDIS knows *where the data is* and *where to put the data*. As a result, these applications need not keep track of either aspect. As such, JDIS provides *the right information to the right people at the right time.*

Passive Aircraft Status System

The JSF AL program must support an intra-aircraft and air-to-base data link for the transfer of status information. The on-board aircraft status system will track aircraft parameters by analyzing problems, collecting status data and then transferring that data to the ground. Current aircraft have the ability to store aircraft diagnostic information; however, they lack the ability to transfer that data automatically to the ground prior to landing. The existing systems all need human intervention in order retrieve the data from the aircraft.

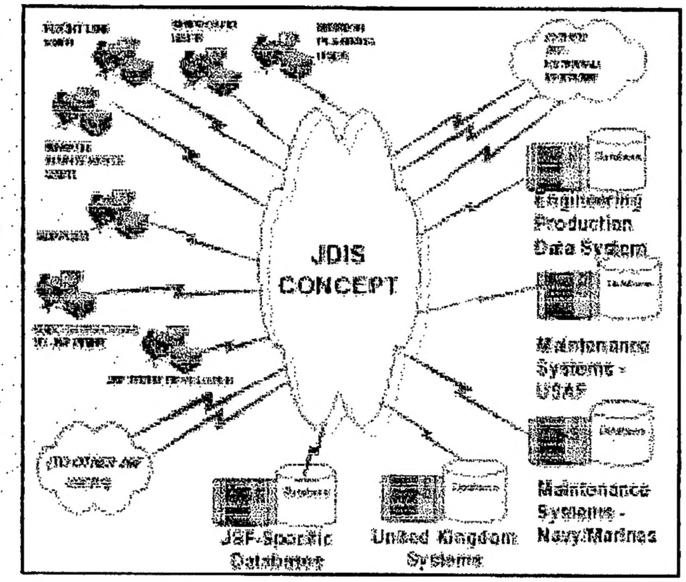

Figure 3. JDIS

The basic structure of PASS gathers the data from systems on the aircraft to a central location and then *bursts* it to a ground station prior to landing. The ground station translates and formats the data for specific applications. That data would most probably go directly

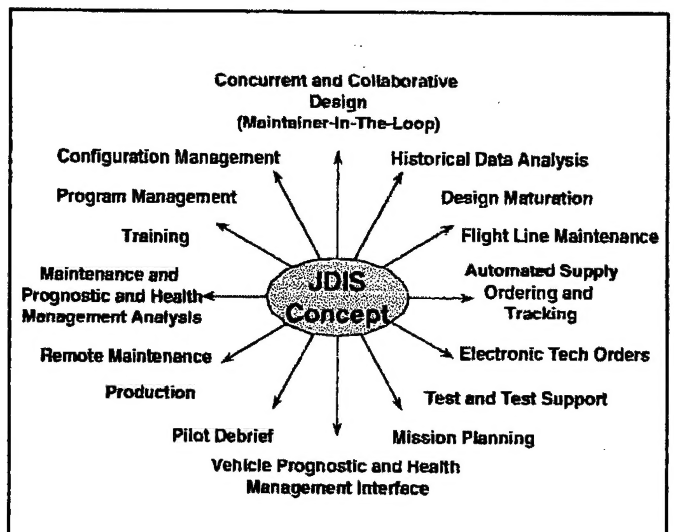

Figure 4. JDIS Application Areas

to the JDIS and be distributed to users as needed. Aircraft maintainers and mission planners can use the information to plan the next mission and coordinate vehicle configuration, stores and consumables.

PASS functions transparently without pilot action prior to aircraft landing. After landing, it transmits pilot verification of vehicle performance and documents pilot input. As part of the JDIS, a great deal of aircraft information can also be accessed by the maintainer. This includes software/hardware configurations, historical problems, modifications completed and the status of on-board systems. It is also envisioned that, in conjunction with JDIS and existing data systems, a data-tracking system could be organized and archived for tracking each aircraft. This system would function much like the Internet does today. Each aircraft would have its own *home page* through which a user could access information specific to that particular aircraft. The entire history of that aircraft, as well as an up-to-date accounting system, displaying the configuration of on-board systems, would be available with just a few keystrokes.

A passive aircraft status system is an absolute necessity in order to support the JSF program office's vision for a truly autonomic logistics system. If applied to existing weapon systems, the Air Force and Navy will benefit through better mission capability rates and better warfighter effectiveness. For industry, this system could provide the same time reductions that can support lower operating costs because of less down time at the airport gate or in the maintenance hangar. If planned experiments prove its feasibility, this system could be retrofitted to current vehicles with existing on-board data capture capability, such as the F-22, F-18E/F and the V-22.

Impact on Logistics

AL will change the way systems are tested. The move to a more effective maintenance force, using two-level maintenance and/or contracting with the commercial sector for maintenance services, will require the migration of a prognostic and diagnostic test capability to the aircraft as well as a more effective and affordable means of off-board repair. Test capabilities (for example, Built-In-Test, Portable Maintenance Aids and Automatic Test Equipment) in present systems give an indication when there is a fault but require the technician to do a large portion of the diagnostic analysis and maintenance work to get to the malfunctioning part of the system. For the AL system to work efficiently, a good portion of the diagnostic work must already be accomplished, with the technician at the flight line completing the final work in the maintenance process. To speed up the cycle, PASS must be functioning to decrease the time needed to turn the aircraft around and be prepared for the next mission. JDIS must effectively manage the on-board and off-board maintenance information to provide all technicians and maintenance organizations *real timely* information access. The definition of real timely is *information must be accessible at the time it is needed.* In the case of repair at a remote site or depot, it must be available when the malfunctioning part arrives. For flight-line repair, it must be available prior to aircraft landing.

Support Community

The support community, as a whole, will play a major role in developing the AL system. In past programs, the support systems have always tended to take a backseat to the performance parameters of the aircraft. The JSF program has placed increased emphasis on PHM, its role in supporting the aircraft and the cost implications to the aircraft over its total life. The JSF support system is being designed in a coordinated manner. The on-board and off-board portions of the support systems are being designed and trade-offs made to optimize the support systems' performance. Tools are in place to anticipate and integrate future changes in operations and technology.

Supply and Acquisition

Since there will be a number of customers of some diversity, how are all these customers to be supplied with needed parts and services? The answers may be found in business practices seen in the commercial sector. Presently the Services each have their own supply systems. They also have their own individual aircraft, most of which are Service unique. The JSF, on the other hand, will have a *core of parts* that will be common over a number of variants. These core parts will be supplied by one or more companies and should be available to the Services via their supply system. One of the fundamental tenets of the JSF program, however, is use of the JDIS information conduit, making information transparent to the user. That means, for example, if a technician at an Air Force base orders a part from supply, it could potentially come out of a Navy warehouse.

One of the underlying factors in supply actions is the PHM system interface to acquisition systems and the ordering of parts when PHM is predicting an impending failure. We must ensure that PHM algorithms for predicting failures are accurate, verified and validated and must not task the supply system for resources that are not required. There will have to be firewalls and safeguards designed to ensure the system does not short-circuit and unnecessarily deplete the supply system of parts.

Integrated Diagnostic Virtual Test Bench

We are operating in a market driven by economy and rapidly changing technology. Customers in the commercial market are demanding better and quicker service. There is no reason that customers in the military sector should demand anything less. How do we change the business practices that are presently in place for military customers? How can we tailor the AL system to give it the ability to decrease the military customer lead time and still provide the latest technology in our weapon systems? One of the answers to this question may be the Integrated Diagnostics Virtual Test Bench (IDVTB).[7] The IDVTB is a design/design maturation tool that supports the development of an integrated diagnostic, maintenance, mission planning and logistics system throughout the life cycle of a weapon system. IDVTB will facilitate integration by enabling the balance between existing support infrastructures/equipment and emerging support systems and equipment.

Modeling and Simulation

In the world of autonomic logistics design, a tool set is needed in which multiple discrete events can take place concurrently. The execution of events being controlled by predetermined rules, running under a global architecture, introduces a complex set of dependencies. Accurate solutions

are possible by using simulations that closely mirror the real word in a virtual environment and provide users and managers the ability to visualize the operation of their systems early and often throughout the design cycle. The modeling and simulation functions need to be described and understood clearly before the virtual environment can be designed, simulated and tested against a physical case. The high-level concepts are clear; however, implementation of a multiparadigm simulation is still in its infancy. Additionally, compliance with the Defense Modeling and Simulation Office High-Level Architecture (HLA) may prove to be a formidable problem. Yet such a tool is needed. Industry and government must work together to mature tools in order to develop multiparadigm simulations, virtual reality full motion models, tools for developing models of the full mission and support environment and HLA standards. The IDVTB is the first step in this direction.

Conclusion

Before we field the AL system, a pilot operation needs to be performed to serve as an experiment and to prove the technical feasibility of the system. This will need to encompass the entire spectrum of on-board PHM, off-board repair, information management at all levels and interaction with the supply and acquisition systems. Simulation may be the affordable solution to answering the questions to the problems that we have not as yet discovered. In order to create this type of simulation, there will have to be a value-added partnership created to integrate both government and commercial entities as a set of independent companies that are working closely together to interface and integrate all the parts of the AL system.

Notes

1. *JAST Advanced Integrated Diagnostic Study*, Final Report, 31 Mar 95.
2. *JAST Advanced Strike Integrated Diagnostics*, Final Report, 1 Nov 96.
3. *Self-Repairing Flight Control System Volume I: Flight Test Evaluation on an F-15 Aircraft*, WL-TR-91-3025, August 1991.
4. *Flight Control Maintenance Diagnostic System*, WL-TR-93-3022, March 1993.
5. Smith, G, J.B. Schroeder, S. Navarro and D. Haldeman, "Development of a Prognostics and Health Management Strategy for the Joint Strike Fighter," Proc. of AUTOTESTCON, September 1997, 676-682.
6. Smith, G., J.B. Schroeder, S. Navarro and D. Haldeman, "Development of an Integrated Diagnostic Strategy to Support Autonomic Logistics," Proc. of Air Force Logistics Symposium, March 1997
7. Navarro, S., L. Gearhart, G. Smith and J.B. Schroeder, "The Integrated Diagnostics Virtual Test Bench," Proc. of AUTOTESTCON, September 1997, 683-687.

Gary Smith is a Mechanical Engineer in the Advanced Technology Division at the Aeronautical Systems Center collocated with the Air Force Research Laboratory Air Vehicles Directorate. J. B. Schroeder is currently the Aging Aircraft Smart Diagnostics Project Manager and is a member of the Joint Strike Fighter Advanced Diagnostics IPT. He is assigned to the Air Force Research Laboratory, Control Systems Development Branch of the Flight Systems Division at Wright-Patterson AFB, Ohio. Barbara L. Masquelier is the Senior Logistics Engineer in the Logistics Readiness Branch of the Air Force Research Laboratory at Wright-Patterson AFB, Ohio.

JL

Integrated Logistics System—Supply

Second Lieutenant Richard E. Mills, Jr.

The Air Force selected the 42d Supply Squadron at Maxwell AFB, Alabama, as the test site for the Integrated Logistics System-Supply (ILS-S). ILS-S replaces the Standard Base Supply System (SBSS), the current legacy system that has been in operation for more than 30 years.

> Our work with the Standard Systems Group and Lockheed Martin developing this next generation supply computer system will ensure supply units throughout the world receive the best system possible to address today's and future demands,

said Staff Sergeant Mike Brown, 42d Supply Squadron local area network specialist.

ILS-S is a Windows-based program that is easier to operate than the SBSS, according to Major William Predeau, 42d Supply Squadron Management and Systems Flight Chief. It provides the supply organization with total asset visibility for all property in storage, in transit and at other bases throughout the Air Force.

"It will decrease time, money and manpower needed to support base supply customers," said Predeau. Many tasks accomplished in today's SBSS system require several screens to complete. ILS-S will take these same tasks and accomplish them from one input screen.

The new ILS-S allows supply personnel to meet changing Air Force needs because it can be expanded as demands and technology change. Updating information in ILS-S will be easier and less time consuming than with the SBSS.

ILS-S will have the capability to allow the customer to place an order from a desktop computer, thus eliminating the current requirement to call supply's customer service. Although this capability is several years away, when it becomes available, it will create a seamless integration with all supply customers, eliminate the middleman—in this case, supply—and free supply personnel for other tasks.

One hundred fifty personnel, inside and outside of the supply complex, will be trained in the use of the new system. "Our in-house training team has created an in-depth program to ensure our personnel are fully qualified on all aspects of the ILS-S and are prepared to assist with the worldwide implementation," said Staff Sergeant Hayden Pickett, 42d supply clerk. Trainees get experience processing transactions in the new system and are given the opportunity to provide comments on system efficiency and recommend changes to the Standard Systems Group. Picket said:

> ILS-S enhanced capabilities using the Windows-based environment is an overdue upgrade to our current legacy system, SBSS. In the 42d Supply Squadron, we are excited to have the opportunity to help test the logistics system that will take the Air Force into the next millennium.